Science Education in the 21 Century

Using a scientific approach to teach science

Carl Wieman, Univ. of Colorado

I) Data on effectiveness of traditional science teaching.

II) Useful results/principles from research on effective learning.

III) Some examples of technology that make it easier to implement these principles.

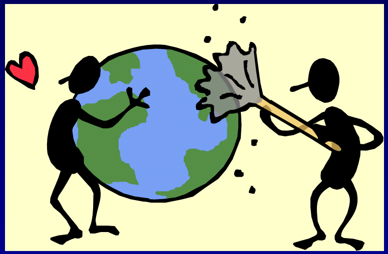
(CU physics & chem ed. research, W. Adams, K. Perkins, K. Gray, L. Koch, J. Barbera, S. McKagan, N. Finkelstein, S. Pollock, R. Lemaster, S. Reid, C. Malley, M. Dubson...
$$ NSF, Kavli, Hewlett)

Science education different, more important purpose than in the past.

Not just for scientists

- Survival of world.

Wise decisions by citizenry on global (technical) issues.



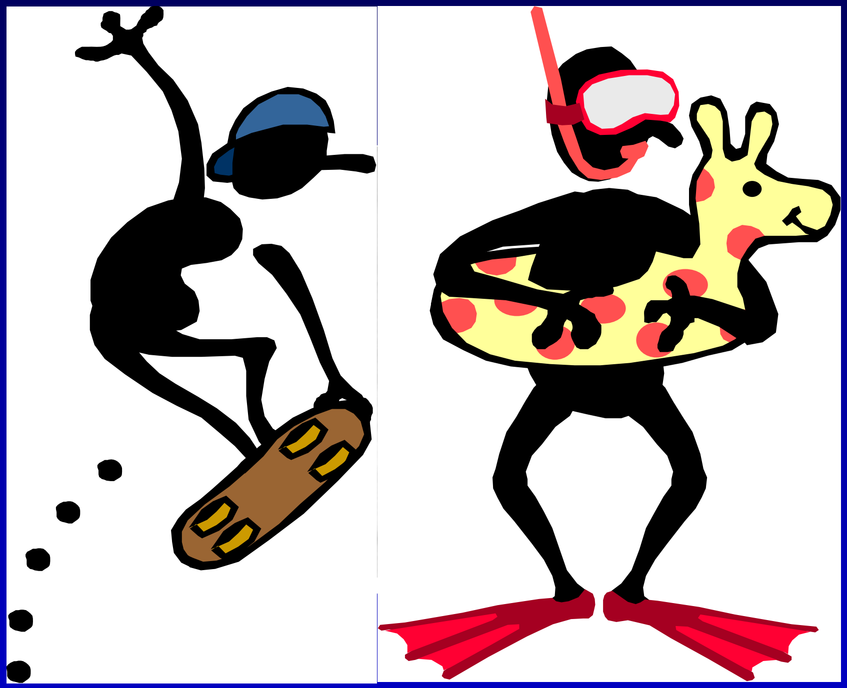
- Workforce in High-Tech Economy.

Need to make science education effective and relevant for large fraction of population!

and diverse!

Essence of an "effective education".

Transform how think--

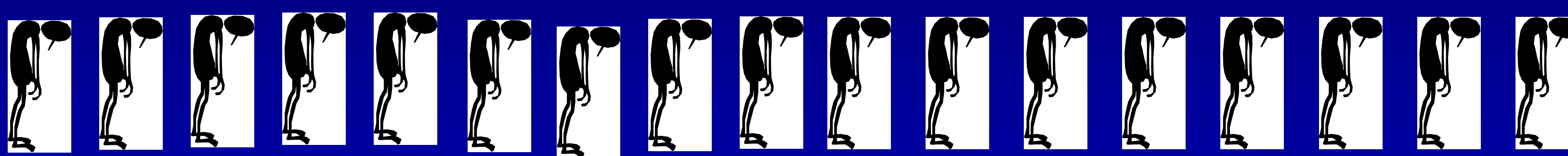


Think about and use science like a scientist.

<u>How to teach science</u>: (I *used many years)*

Think very hard about subject, get it figured out very clearly.

Explain it to students, so they will understand with same clarity.

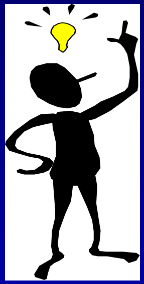


???

grad students

Why, after 17 yrs of success in classes, do students come into lab so clueless about physics?

but 2-4 years later, are expert physicists???



Approach as science problem.

What do we know about how people learn, particularly science?

⇒ above results actually makes sense

II. Some data on effectiveness of traditional approach to science teaching.
lecture, textbook homework problems, exams

(most data from intro university physics, all consistent with other subjects, other levels.)

1. Retention of information from lecture.

2. Conceptual understanding.

3. Beliefs about science.

1. Lecturing and retention

I. Redish- interviewed students as came out of lecture.
"What was the lecture about?"

unable to say anything but vaguest generalities

II. Rebello and Zollman- had 18 students answer six questions, then told them to **get answers to these 6 questions from following 14 minute lecture.** (Commercial video, highly polished)

Most questions, less than one student able to get answer from listening to lecture.

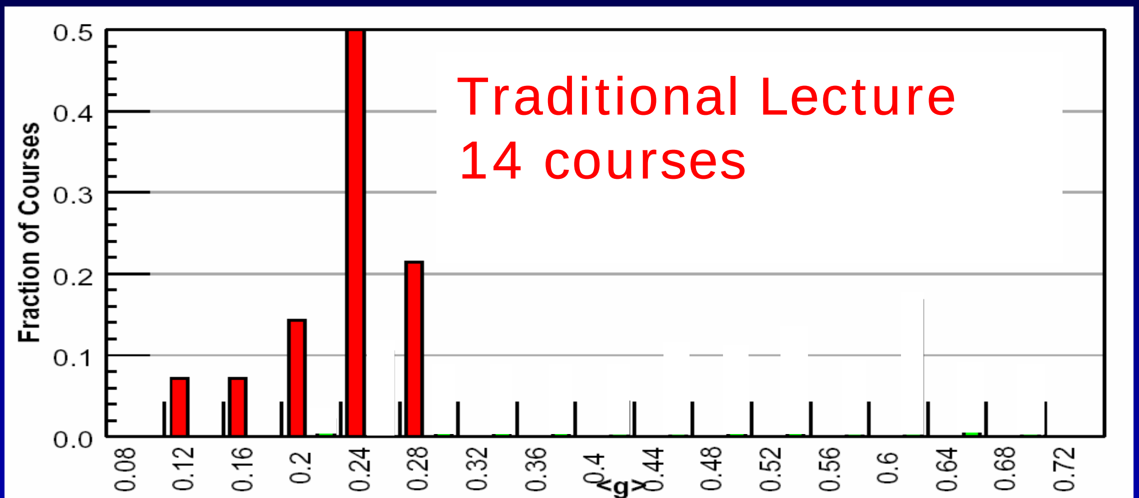
III. Wieman and Perkins- 15 minutes after nonobvious fact told to students in lecture with illustration, gave simple multiple choice test to see if remembered.

~10% get correct (even in phys. dept. colloq.)

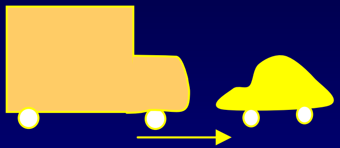
2. Conceptual understanding.

Learned in traditional intro physics course?

- Force Concept Inventory-basic concepts of force and motion



Fraction of unknown basic concepts learned



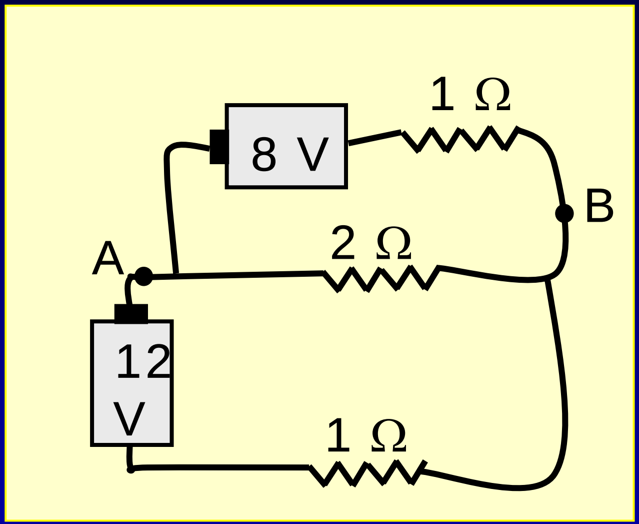
Learn <30% of concepts did not already know.
Lecturer quality, class size, institution,...doesn't matter!

R. Hake, "…A six-thousand-student survey…" AJP 66, 64-74 ('98).

2. Conceptual understanding (cont).

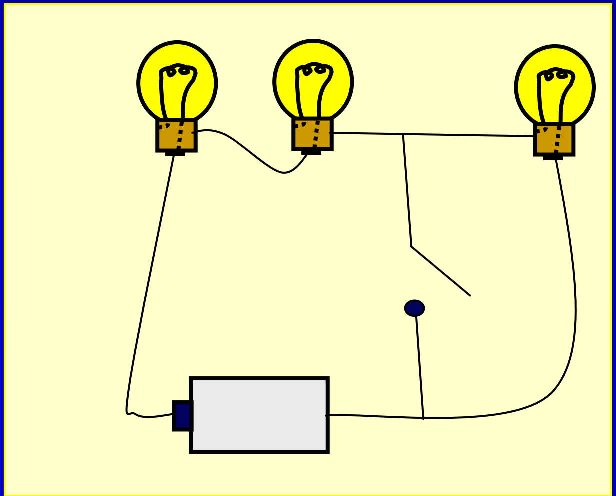
electricity

Eric Mazur (Paired problems)



Most students can calculate currents and voltages in complex circuit.

BUT, not predict brightness of bulbs when switch closed.



Solving test problems, but **not** thinking like expert!

3. Beliefs about physics and problem solving (*measured*)*

Novice

Content: isolated pieces of information to be memorized.

Handed down by an authority. Unrelated to world.

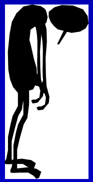
Problem solving: pattern matching to memorized arcane recipes.

Expert

Content: coherent structure of concepts.

Describes nature, established by experiment.

Prob. Solving: Systematic concept-based strategies. Widely applicable.



nearly all physics courses ⇒ *more* novice

ref. Redish et al, CU work--Adams, Perkins, MD, NF, SP, CW

*adapted from D. Hammer

Science Education Research Conclusions 1:

•Not easy to know what students actually are (and are not) learning.

•Most students "learning" rote memorization of facts and problem solving recipes, not useful understanding.

most also learning that science is uninteresting and irrelevant

III. What does research tell us about principles that are important for more effective learning?

Three generally applicable examples

a. cognitive load

b. role of attitudes and beliefs

c. developing expert competence

apply to technical talks as well as classes

Results when put into practice

1. Retention of information from lecture

   ~~10% after 15 minutes~~ ⇒ >90 % after 2 days

2. Conceptual understanding gain

   ~~25%~~ ⇒ 65%

3. Beliefs about physics and problem solving

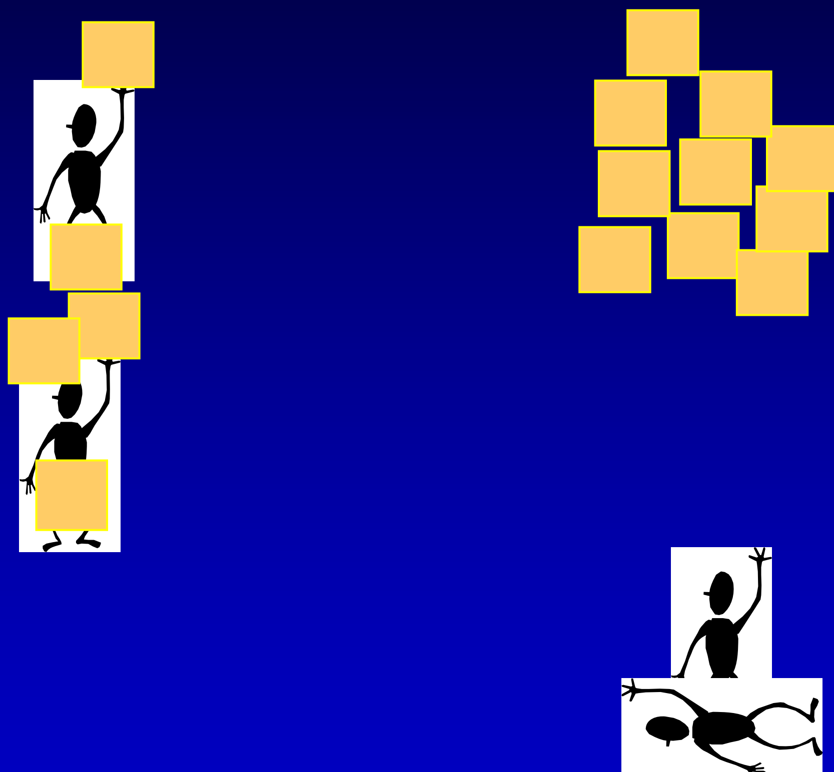
   ~~significant drop~~ ⇒ small improvement

examples-- using research on how people learn

a. Cognitive load-- best established, most ignored.

Mr Anderson, May I be excused? My brain is full.

a. Cognitive load-- every bit more costs.



~7 items short term memory, process 4 ideas at once.

Typical class, MUCH more than brain can process.

b. Importance of student beliefs about science and science problem solving

my group studies-- new survey instrument.

Lots of data!

- Beliefs ←→ content learning
- Beliefs ←→ choice of major/retention
- Teaching practices → students' beliefs

Normally decline (less like expert) after undergrad science class (phys or chem).
BUT, can avoid decline if explicitly address beliefs.

Why is this worth learning?
How does it connect to real world?
Why does this make sense?
How connects to things you already know?

c. Research on developing expert competence

Expert competence =

- factual knowledge
- **Organizational structure** ⇒ effective retrieval and use of facts

or ?

just pouring in more facts can hinder rather than help

- **Ability to monitor own thinking** ("Do I understand this? How can I check?")

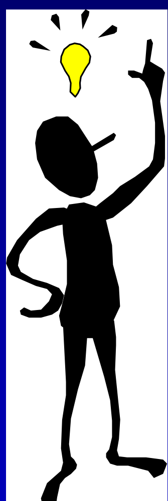
- New ways of thinking--require active mental construction.
- Built on prior thinking.

To develop, needs to be explicit part of learning process

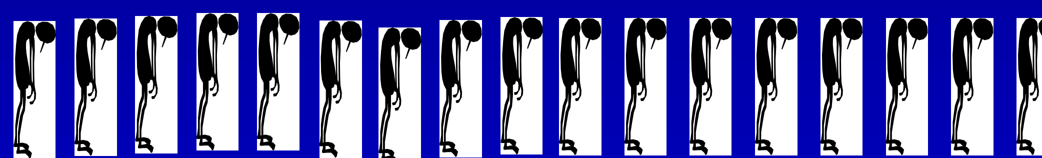
(Reexamine) How to teach science:

Think very hard about subject, figure out very clearly. Explain it to students, so they understand with same clarity.

me vs students



- massively heavier cog. load
- novice beliefs about why to learn, how to learn.
- no organizational structure



general principle ⇒people learn by creating **own** understanding. Effective teaching: facilitate by guiding that creation.

III. Some technology that can help implement principles.*

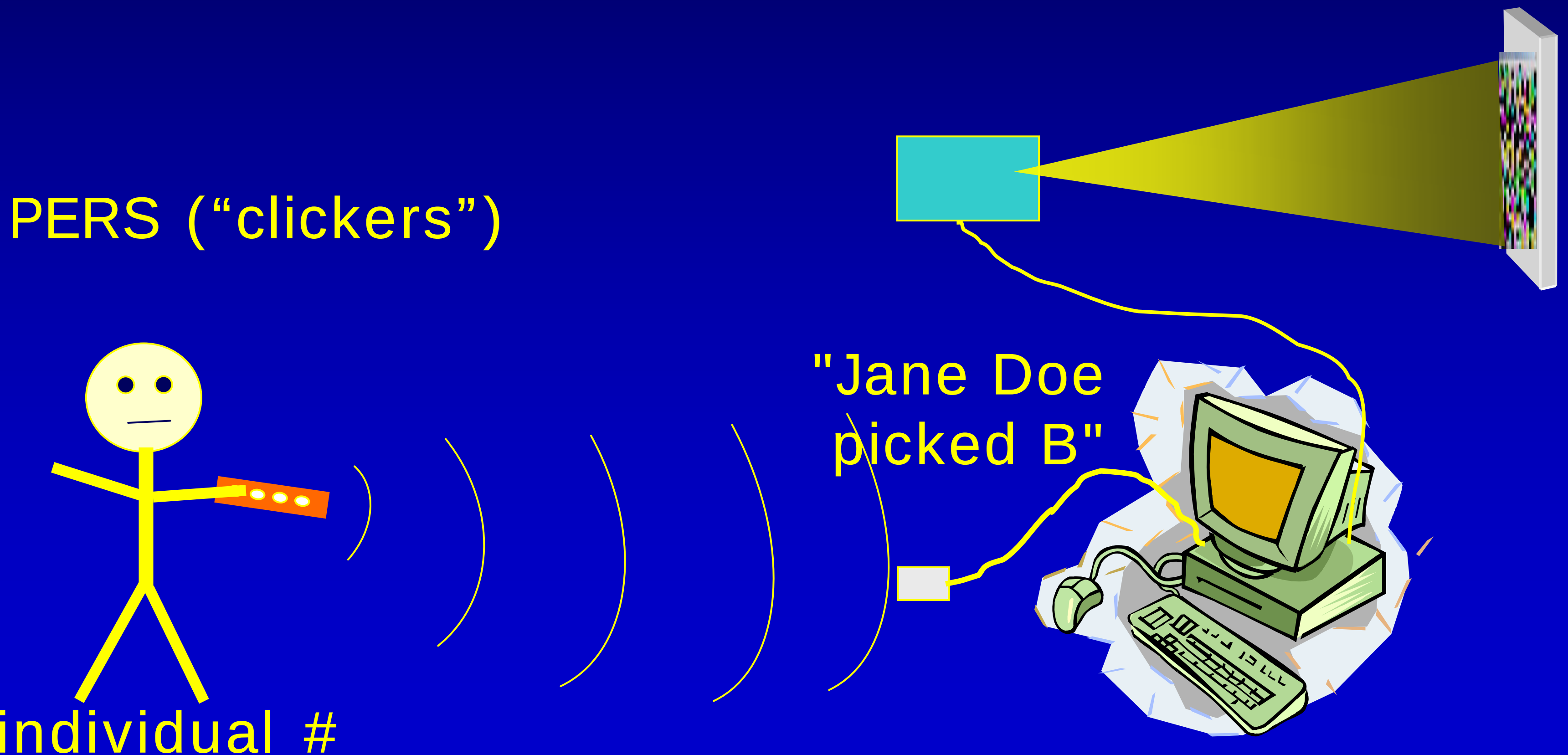
a. student personal response systems
b. interactive simulations

* work from Col. sci. ed. research group

III. Some technology that can help.

(when used properly)

- Personal electronic response systems--facilitate active thinking and useful guidance. Relatively cheap.



15 minutes after telling and showing students how wooden back of violin is what produces sound they hear...

"Sound you hear from a violin is produced ..."
a. mostly by strings, b. mostly by wood in back, c. both equally, d. none of above.

students click in responses, then display histogram

clickers-

Used properly transforms classroom.
Dramatically improved engagement, discourse, number (x4) and distribution of questions.

Not automatically helpful--
Only require students to commit to an answer
(accountability + peer anonymity+ fast feedback)

Key to educational effectiveness
use guided by how people learn

Clicker questions and associated discussion:

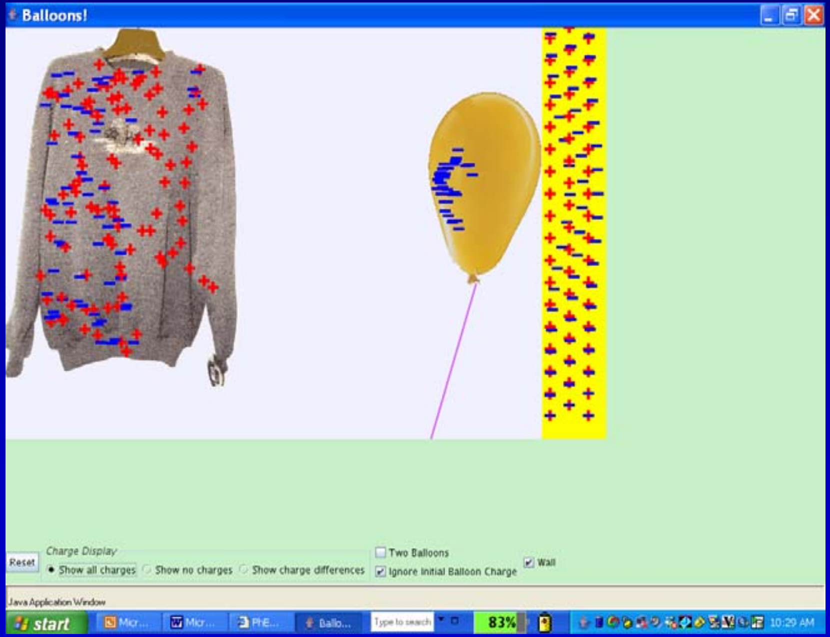
- Focus students on processing ideas, "organize and apply"
- Communication and feedback (student-instructor, student-student)
- student consensus-group discussions (& listen in)

Interactive simulations

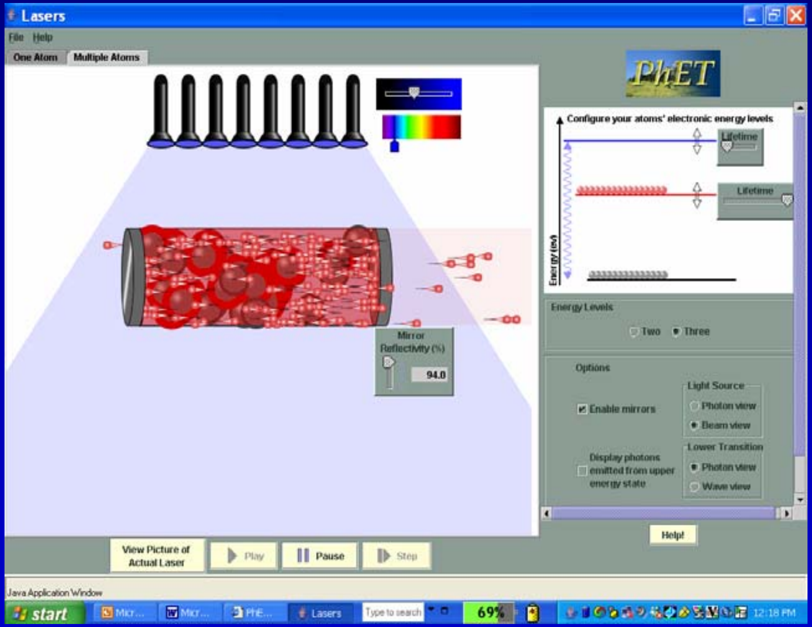
phet.colorado.edu

Physics Education Technology Project (PhET)

Wide range of physics topics and some chem., well tested, free online or download. Run in regular web-browser.
Use in lecture, lab, homework. (often better than reality!)



balloon and sweater



laser

supported by: Hewlett Found., Kavli, NSF, Univ. of Col., and A. Nobel

examples:

balloon and sweater

moving man

wave on string

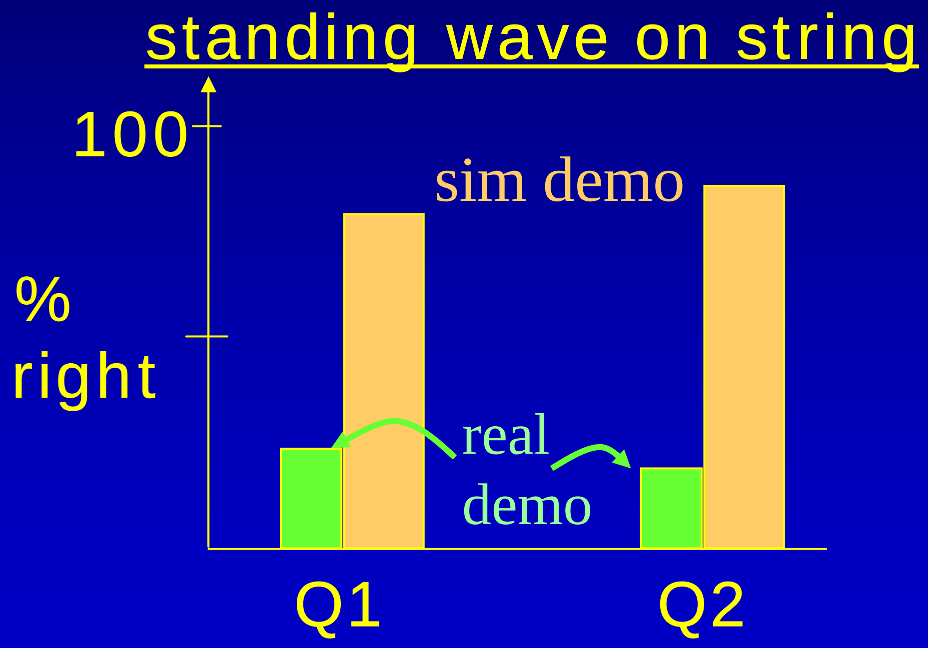
circuit construction kit

each illustrate a unique pedagogically valuable characteristic of interactive simulations

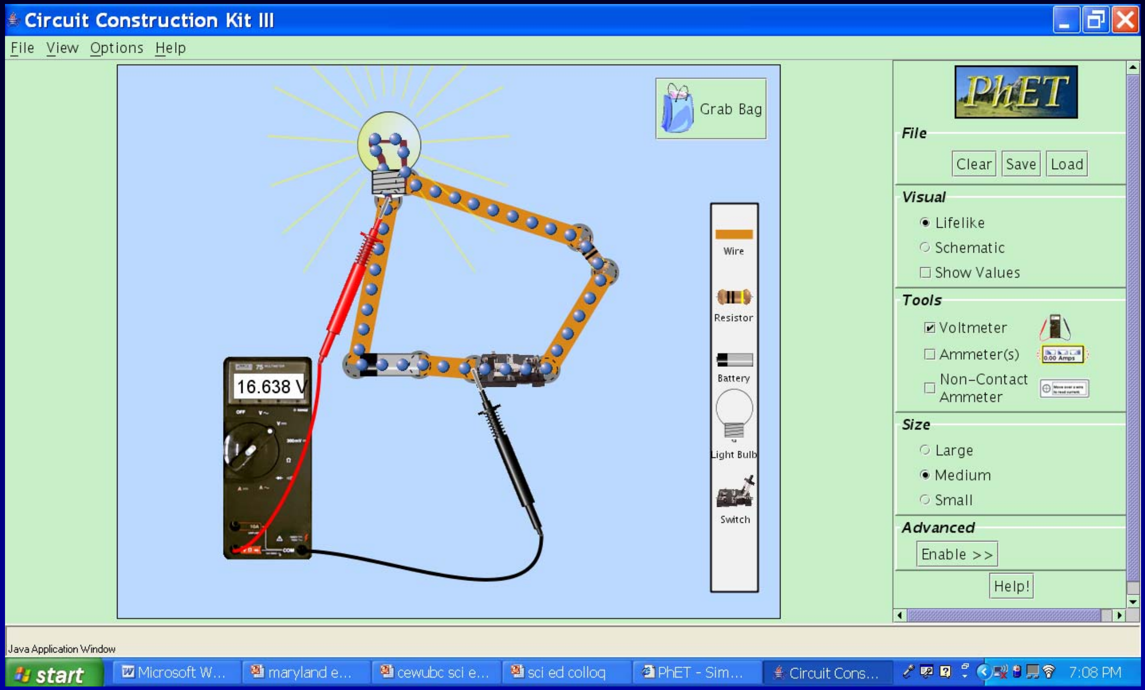
Research on design and effectiveness of simulations.

(Wendy Adams, Kathy Perkins, Noah F., et al)

1. Substantial improvement on concept questions when used in lecture vs real demos or static images.



CCK



Students learn to build and understand real circuits better with sim than with real equipment!
Finkelstein et al Phy. Rev. PER 1,1

real world not necessarily best pedagogically,
experts and novices see very differently.
Need to be very sophisticated to see simplicity.

Summary:
Need new, more effective approach to science ed.

Solution: Approach teaching as a science

- *Practices and principles based on good data*
- *Effective use of technology*
- *Disseminate and copy what works.*

Good Refs.:
NAS Press “How people learn” , "How students learn"
Mayer, “Learning and Instruction” (ed. psych. applied)
Redish, “Teaching Physics” (Phys. Ed. Res.)
Wieman and Perkins, Physics Today (Nov. 2005)

CLASS belief survey: CLASS.colorado.edu
phet simulations: phet.colorado.edu

b. Importance of student beliefs about science and science problem solving

Our new beliefs survey (*CLASS.colorado.edu)*
(similar to MPEX but more general)

Strongly Disagree	1	2	3	4	5	Strongly Agree

I think about the physics I experience in everyday life.

After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.

- <10 minutes, Give online pre- and post- instruction (>10,000 stds)
- Score agree (% favorable) or disagree with expert view

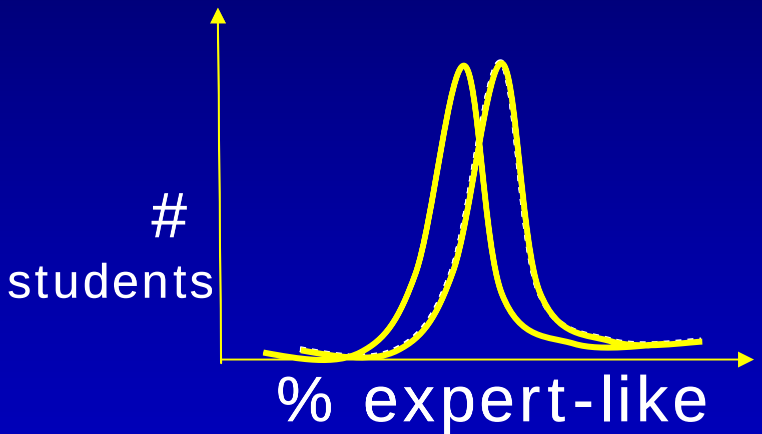
Lots of data!

- Beliefs ←→ content learning
- Beliefs ←→ choice of major/retention
- Teaching practices → students' beliefs

b. Teaching practices and beliefs

Course Type	Dominant student population	Beliefs (% favorable) Overall Pre	Post
Phys-I (alg)	pre-meds	60%	51%
Phys-I (calc)	sci. & eng.	64%	58%

Decline in beliefs ~all intro physics courses (also chem.)



Teaching practices and beliefs

Avoid decline if minimal effort to explicitly address beliefs.

		pre	post
Phys I	premeds	56%	58%
Phys I	sci & eng	64%	66%

Why is this worth learning?
How does it connect to real world?
Why does this make sense?
How connects to things you already know?

Interesting new result- students know expert beliefs and problem solving approaches, but don't accept as valid. (particularly women)